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Shear Behavior of Self Compacting Concrete

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ABSTRACT

Twelve self compacting concrete (SCC) beams were cast to investigate the shear behavior under two concentrated load. All beams have a constant longitudinal steel ratio of (0.02065) and constant gross section area of (17000)mm^2. The tested beams were divided into two group with and without stirrups. The first group contained three beams without stirrup at different value of compressive strength (f_c') with the same value of clear span to the effective depth ratio (ln/d), while the second group contained nine beams with stirrups. This group was divided into three series according to the compressive strength (f_c') each series contained three beams at different value of clear span to effective depth ratio(ln/d).It was found that the ultimate shear strength predicated from ACI 318-08 is lesser than the experimental values. The ultimate shear strength for SCC beams with stirrups increase about 15 73.%.30.69 %and 25.633 % when the compressive strength increased from (29.36 to 49.2 MPa) at clear span to effective ratio (ln/d) 6.164, 5.479 and 5.0 respectively. The ultimate shear strength for SCC beams without stirrups increased about 31.25% when the compressive strength increased from (29.36 to 49.2 MPa),the ultimate shear strength of SCC beams with stirrups increased about 29.966%,38.775%and 37.85% when the clear span to the effective depth (ln/d) decreased from (6.164 to 5.0) at compressive strength (fc) 29.36, 41.42 and 49.2 MPa respectively, the ultimate shear strength of SCC beams with stirrups increased about 85.41%, 68.96% and 63.492% as compared with ultimate shear strength without stirrups at compressive strength 29.36,41.42 and 49.2 MPa respectively.

Key words: shear strength, rectangular section, without stirrups, with stirrups, self compacting concrete

سلوك العتبات الخرسانية الذاتية الرص تحت تأثير أحمال القص

الخلاصة

اثنتا عشر عتبة خرسانية ذاتية الرص صممت وفحصت تحت حملين مركزين . جميع العتبات تحوي عل نسبة حديد تسليح واحدة هي (0.02065) ومساحة المقطع العرضي هي (17000) ملم^2.

العتبات المفحوصة قسمت الى مجموعتين مجموعة مسلحة بحديد تسليح القص (الاتاري) والاخرى غير مسلحة بحديد تسليح القص (الاتاري).

المجموعة الاولى تحوي على ثلاث عتبات خرسانية ذاتية الرص بدون حديد تسليح القص (الاتاري) بمقاومة انضغاط مختلفة بينما المجموعة الاخرى تحوي على تسعة عتبات خرسانية ذاتية الرص قسمت الى ثلاثة متواليات حسب مقاومة الانضغاط كل متوالية تحوي على ثلاث عتبات بنسب مختلفة من الطول الصافي الى العمق الفعال.

بعد نتائج الفحص وجدت ان مقاومة القص القصوى المستحصلة من المدونة الامريكية (318M-08) اقل من النتائج المستحصلة من الجانب العملي, وان مقاومة القص للعتبات الخرسانية الحاوية على حديد تسليح الاتاري تزداد بمقدار 15.73% و 30.69% و 25.663% عند زيادة مقاومة الانضغاط من 29.2 نت/ ملم^2 الى 49.2 نت/ ملم^2 عند الطول الصافي الى العمق الفعال 6.164 و 5.79 و 5.00 على التوالي.

ان مقاومة القص للعتبات الخرسانية الغير حاوية على حديد تسليح القص (الاتاري) تزداد بمقدار 31.25 % عند زيادة مقاومة الانضغاط من (29.2) نت/ ملم^2 الى (49.2) نت/ ملم^2 , وان مقاومة القص للعتبات الخرسانية الذاتية الرص الحاوية على حديد تسليح تزداد بمقدار 22.966% و 38.775% 37.85% عند نقصان نسبة الطول الصافي الى العمق الفعال من (6.164 الى 5.0) بمقاومة انضغاط 29.36 نت/ ملم^2 و 41.42 نت/ ملم^2 و 49. نت/ ملم^2 على التوالي.

ان مقاومة القص للعتبات الخرسانية الحاوية على حديد تسليح القص(الاتاري) تزداد بمقدار 85.41 % و 68.9% و 63.492% مقارنة مع العتبات الخرسانية الغير حاوية على حديد تسليح القص(الاتاري) عند مقاومة انضغاط 29.36 نت/ ملم^2 و 41.42 نت/ ملم^2 و 49.2 نت/ ملم^2 على التوالي.

1. Introduction

Self compacting concrete (SCC), is a new kind of high performance concrete (HPC) with excellent deformability and segregation resistance. It is a flowing concrete without segregation and bleeding, capable of filling spaces in dense reinforcement or inaccessible voids without hindrance or blockage. The composition of SCC must be designed in order not to separate and not to excessively bleed. Concrete strength development is determined not only by the water-to-cement ratio, but also is influenced by the content of other concrete ingredients like cement replacement material and admixtures(1).

2. Research significance

Concrete has been used in the construction industry for centuries. Many modification and developments have been made to improve the performance of concrete, especially in term of strength and workability. Engineers have found new technology of concrete called self compacting concrete. The principle objective of the work described in this study to investigate and to get more information and better understanding of the behavior of shear strength of self compacting concrete beams .

3. Test program

3.1 Description of specimens:

The beams are divided into three groups according to the overall length (1000, 900 and 830 mm). The cross section has overall dimension of 100 mm (width of beams) by 170 mm (total depth). The longitudinal steel reinforcement consist of six bar (diameter of the bar 8 mm, with area of 50.265mm^2) laid in two layer at the bottom and two bar (diameter 4 mm, area of 12.566 mm^2) laid in one layer at the top. The internal steel stirrups are 4 mm in diameter (12.566 mm2) at spacing 73 mm center to center as shown in Fig.(1), the test set-up is shown in Fig. (2) and the total description of the beams which used in this study are listed in Table (1).

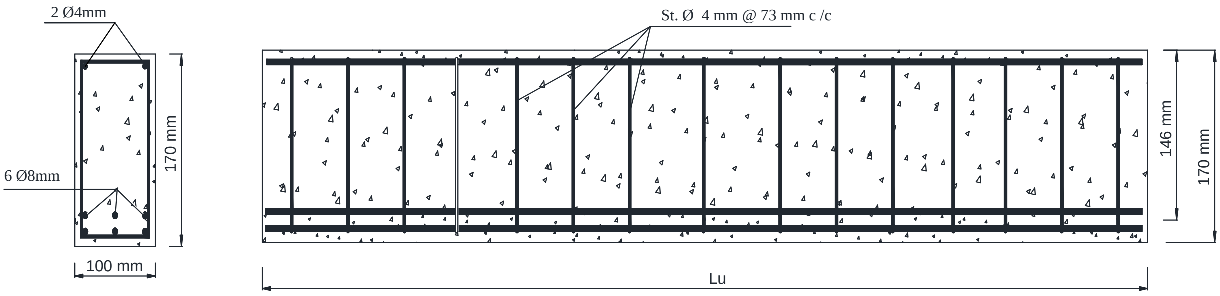

Fig.(1) Details of specimens all dimensions in mm: (A) elevation ; (B) cross-section

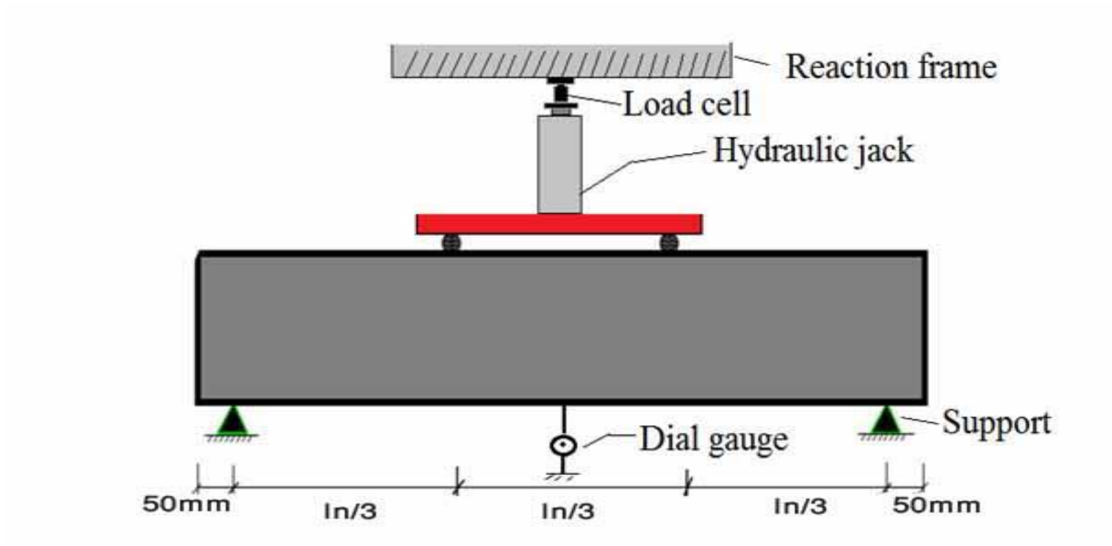

Fig.(2) Schematic diagram of test set-up

Table (1): Total description of the tested beams

Group	Beam	Comp. strength (f'_c)MPa	Clear span (ln)mm	Effective depth (d)mm	Clear span to effective depth ratio (ln/d)
Beams without stirrups	A10	29.39	900	146	6.16
	B10	41.4	900	146	6.16
	C10	49.2	900	146	6.16
Beams with stirrups	A11	29.39	900	146	6.16
	A12	29.39	800	146	5.47
	A13	29.39	730	146	5
	B11	41.4	900	146	6.16
	B12	41.4	800	146	5.47
	B13	41.4	730	146	5
	C11	49.2	900	146	6.16
	C12	49.2	800	146	5.47
	C13	49.2	730	146	5

3.2 Materials:

General description and specification of materials used in the test are listed below, tests are made in the Materials Laboratory , College of Engineering Al-Mustansiriya University.:
Cement : Ordinary Portland cement Type I produced at northern cement factory (Tasluja-Bazian) is used throughout this investigation which conforms to the Iraqi specification No. 5/1984(2).
Fine Aggregate: Al-Ukhaider natural sand is used. which complies with the Iraqi Standard Specification No.45/1984(3).
Coarse Aggregate: Crushed gravels maximum size 10 mm from Al-Nibaee area are used in this study. which complies with the Iraqi Standard Specification No.45/1984(3).
Water : Potable water is used throughout this work for both mixing and curing of concrete.
Steel Reinforcement: Deformed longitudinal steel bars with nominal diameter of 8mm and 4mm were used in this study. Reinforcement were tested to determine the yield stress of 8mm and 4mm and those were 400 and 350 MPa receptively
Limestone Powder: A fine limestone powder (locally named as **Al-Gubra**) of Jordanian origin with fineness (3100 gm/cm²) is used to avoid excessive heat generation, enhance fluidity and cohesiveness, improve segregation resistance and increase the amount of fine powder in the mix (cement and filler). According to **EFNARC [4],** the fraction less than 0.125 mm will be of most benefit.

Superplasticizer : for the production of High-Performance Concrete, a superplasticizer is used throughout this study. It is known commercially as **"GLENIUM51"** and it is brought from Degussa Construction Chemicals. It is a new generation of modified polycarboxylic ether. It is suitable for the production of SCC. Also, it is free from chlorides and complies with **ASTMC494** types A and F. It is compatible with all Portland cements that meet recognized international standards [5].

3.2.3 Mix Design for Self-compacting Concrete

Mix proportioning is more critical for SCC than for normal strength concrete (NSC) and high strength concrete (HSC) . Many trials are carried out on mixes incorporating superplasticizer by increasing the dosage of the admixture gradually, adjusting the w/c ratio to ensure the self-compact ability. Tables (2) indicate the mix proportion of SCC mix. For each concrete mix, three cylinder specimens are taken and tested at 28 days, the test result of fresh concrete properties are shown in Table (3) these results are within the acceptable criteria for SCC given by ACI committee-363(6),and indicate excellent deformability without blocking .

Table (2): mix design of SCC mixes by weight

Group	**Cube Strength (f_{cu})(MPa)**	**Cylinder Strength (f'_c) (MPa)**	**W/C Ratio**	Mix proportions (kg/m^3)					L /m^3	
				Cement	**Lsp**	**Total powder**	**Sand**	**Gravel**	**Water**	**Glenium51**
A	36.3	29.36	0.55	346	204	550	743	833	190	6.6
B	51.74	41.42	0.55	474	105.3	357.3	758.4	833	180	8.1
C	59.2	49.2	0.38	535	64	599	814	833	155	18

Table (3): Results of Testing fresh SCC property in experimental work

Mix symbol	Slump flow (mm)	T50 Sec.	L-box (H2/H1)	T20 Sec.	T40 Sec.
A	750	2.6	0.96	1.8	3.5
B	715	3.8	0.90	2.1	3.9
C	685	4.9	0.88	2.3	4.2

Acceptance criteria for Self-compacted concrete (SCC) [7]

NO.	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump flow	mm	650	800
2	T50	Sec	2	5
3	L-Box	(H2/H1)	0.8	1

4. Shear strength of beam in CODE provision:

ACI 318-08 calculate the nominal shear capacity (V_n) of beam as follows(5):

$$V_n = V_c + V_s \qquad \text{……………………. Eq. (1)}$$

$$V_c = \frac{\sqrt{f'_c}}{6} b_w \; d \qquad \text{……………………….Eq. (2)}$$

$$V_c = (\sqrt{f'_c} + 120 \; \ell w V_u d/M_u) b_w d/7 \qquad \text{…………………….. Eq. (3)}$$

$$V_s = Av \; f_y \; d / S \qquad \text{……………………. Eq. (4)}$$

Where:-

V_c and V_s are shear transfer capacity of concrete and shear reinforcement respectively; Mu and V_ud are factored moment and shear force; $\ell_w = As/b_w d$ is the longitudinal bottom reinforcement ratio; As is the longitudinal bottom reinforcement area; b_w is the width of the web; d is the effective depth; A_v is the vertical shear reinforcement area, S is the spacing between the vertical stirrups reinforcement; f_c' is the compressive strength of concrete and f_y the yield strength of shear reinforcement

According to clear span to effective depth ratio (ln/d) the main variable in this research , Eq.(3) will be used since the shear stress at cracking will depend on the bending moment and shear force at critical section ratio (Vud/Mu)and the longitudinal steel ratio (ℓ_w) that lead to reduced the shear crack and improved the ultimate strength.

Table (4) compared the ultimate shear strength obtained from tested of SCC beams with that obtained by using the ACI 318-08 provisions, by the inspection of Table (4) shown below it can be noted that the ultimate shear strength predicated from ACI 318-08 is lesser than the experimental values because of the SCC will improved durability, and increased bond strength[7].

Table (4) comparisons of tested results

Beam	Ultimate shear strength (V_u kN) tested	Nominal shear strength (V_n kN) ACI	V_u tested / V_n ratio
A10	24	16.469	1.457
A11	44.5	34.6	1.306
A12	50.5	34.6	1.482
A13	56.5	34.6	1.658
B10	29	18.588	1.560
B11	49	36.181	1.354
B12	64	36.181	1.768
B13	68	36.181	1.879
C10	31.5	19.798	1.591
C11	51.5	37.391	1.377
C12	66	37.391	1.765
C13	71	37.391	1.898

5. Results

5.1 Load – Carrying capacity of the tested beams

The relationship between the applied load and the deflection for the tested beams is shown in Fig.(3) to Fig.(6). At every stage of loading ,the deflection at mid-span is obtained by dial gage at mid span, it can be noticed that :

- During the early stage of loading no interface slip is recorded and this continue until the applied load is equal to first crack load approximately, Beyond the first crack loading each beams behaved in a different manner.
- The ultimate shear strength of SCC beams with stirrups increased when the compressive strength increased as shown Fig.(7). The ultimate shear strength increase about 15.73%.30.69%and 25.663% when the compressive strength increased from (29.36 to 49.2 MPa) at clear span to effective ratio (ln/d) 6.164, 5.479 and 5.0 respectively as shown in table (5) .
- The ultimate strength of SCC beams without stirrups increased when the compressive strength increased as shown in Fig.(8), the ultimate shear strength increased about 31.25% when the compressive strength increased from (29.36 to 49.2 MPa).
- The clear span to the effective depth ratio (ln/d) has a significant influence on the ultimate shear strength as shown in fig (9), the ultimate shear strength of SCC beams increased about 30%,39%and 38% when the clear span to the effective depth (ln/d) decreased from (6.164 to 5.0) at compressive strength (fc) 29.36, 41.42 and 49.2 Mpa respectively as shown in table (6)
- The ultimate shear strength of SCC beams with stirrups is greater than SCC beams without stirrups as shown in Fig.(10),the ultimate shear strength of SCC beams with stirrups increased about 85.41%, 68.96% and 63.492% as compared with ultimate shear strength without stirrups at compressive strength 29.36,41.42 and 49.2 Mpa respectively, as shown in Table (7).

5.2 Failure mode

As was expected, all the tested beams failed in shear as shown in Fig.(11),the diagonal crack form independently. The beams remain stable after such cracking. Further increase in shear force will cause the diagonal crack to penetrate into the compression zone at the loading point, until eventually crushing failure of concrete occurs there[9].

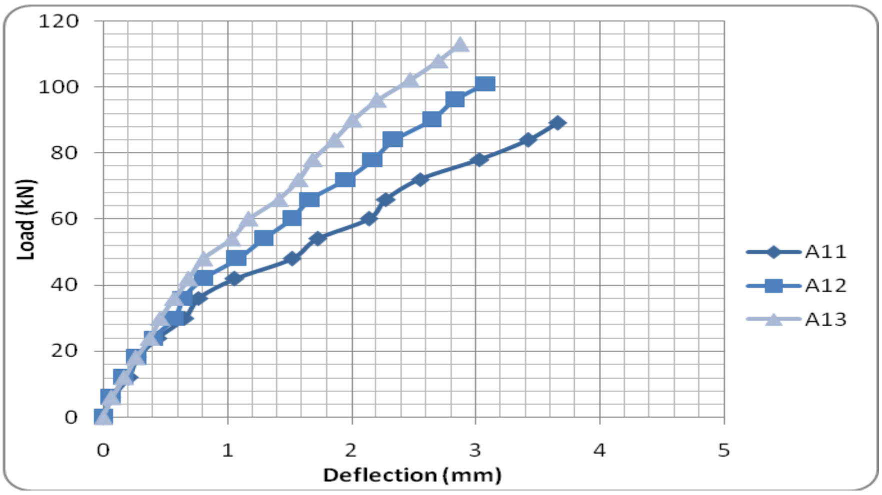

Fig. (3) Load –deflection curve for SCC beams with stirrups at compressive strength (f_c')=29.36 Mpa.

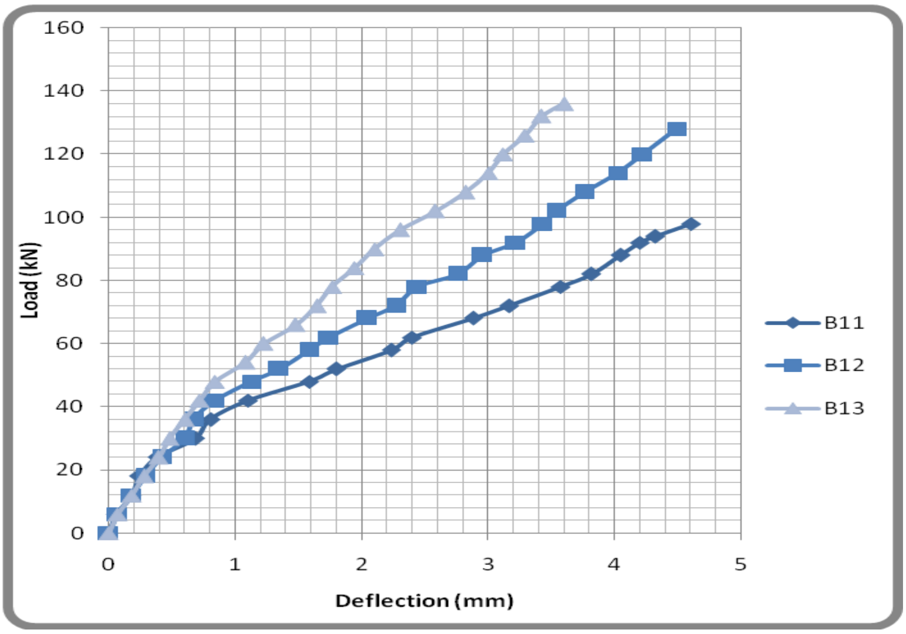

Fig. (4) Load –deflection curve for SCC beams with stirrups at compressive strength (f_c') = 41.42 Mpa.

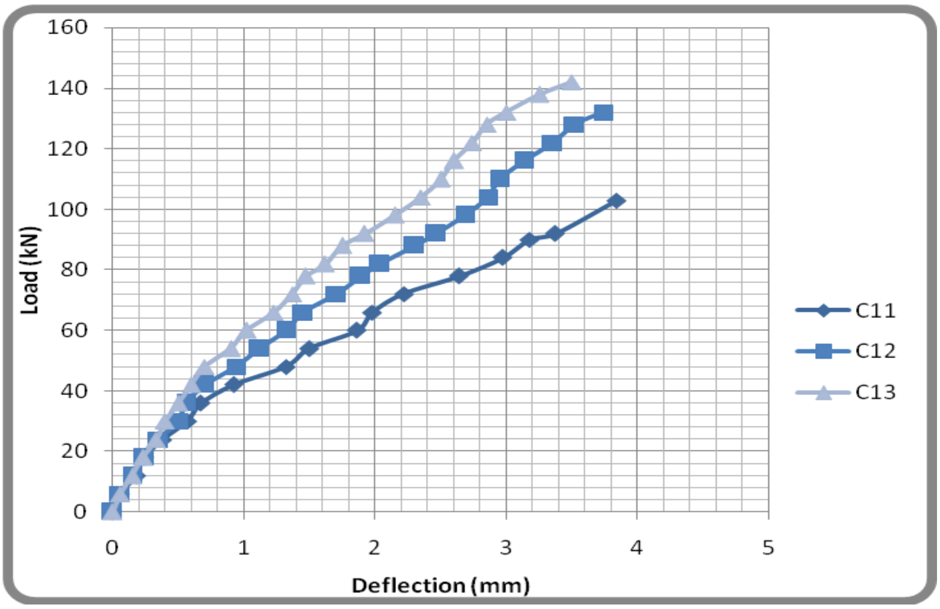

Fig. (5) Load –deflection curve for SCC beams with stirrups at compressive strength (f_c') = 49.2 Mpa.

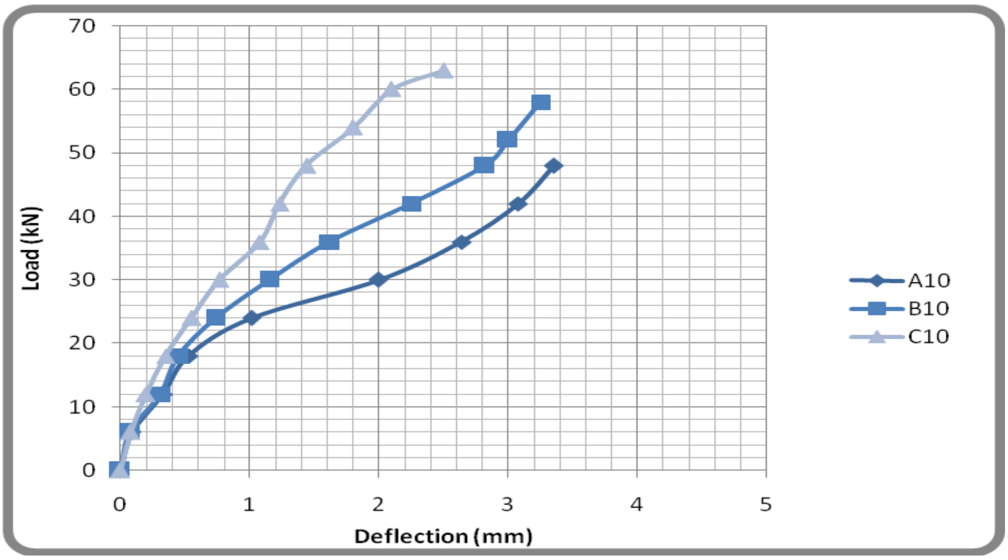

Fig. (6) Load –deflection curve for SCC beams without stirrups at clear span to effective depth ratio (ln/d)=6.164.

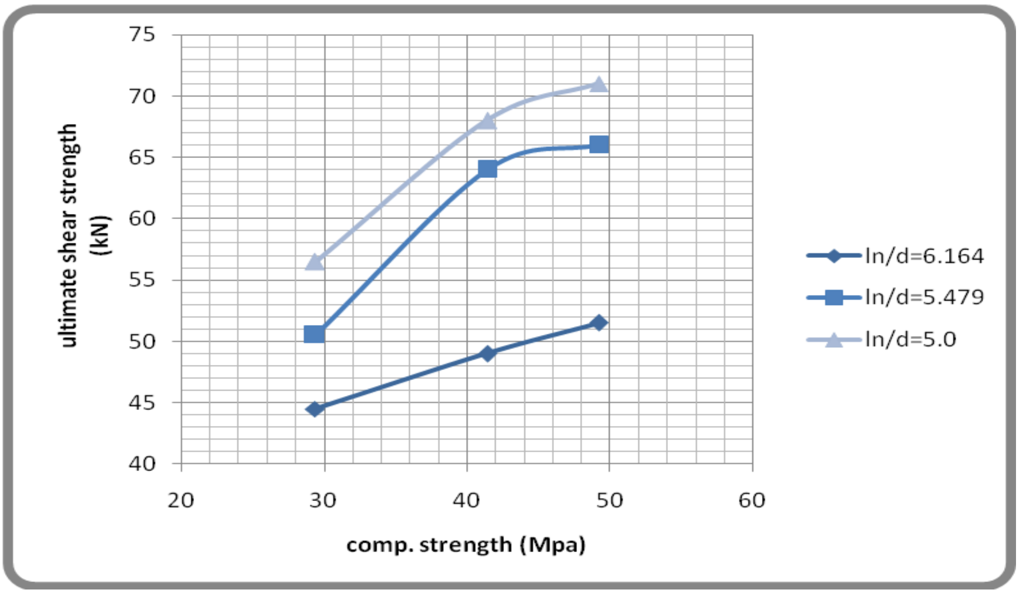

Fig. (7) Effect of compressive strength (f'_c) for SCC beams with stirrups on the ultimate shear strength.

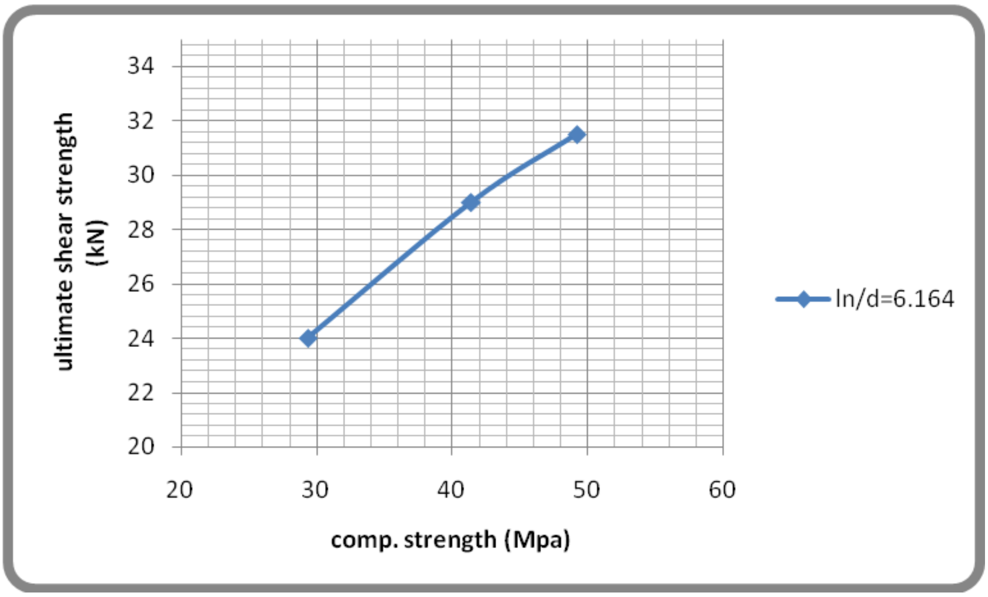

Fig. (8) Effect of compressive strength (f'_c) for SCC beams without stirrups on the ultimate shear strength.

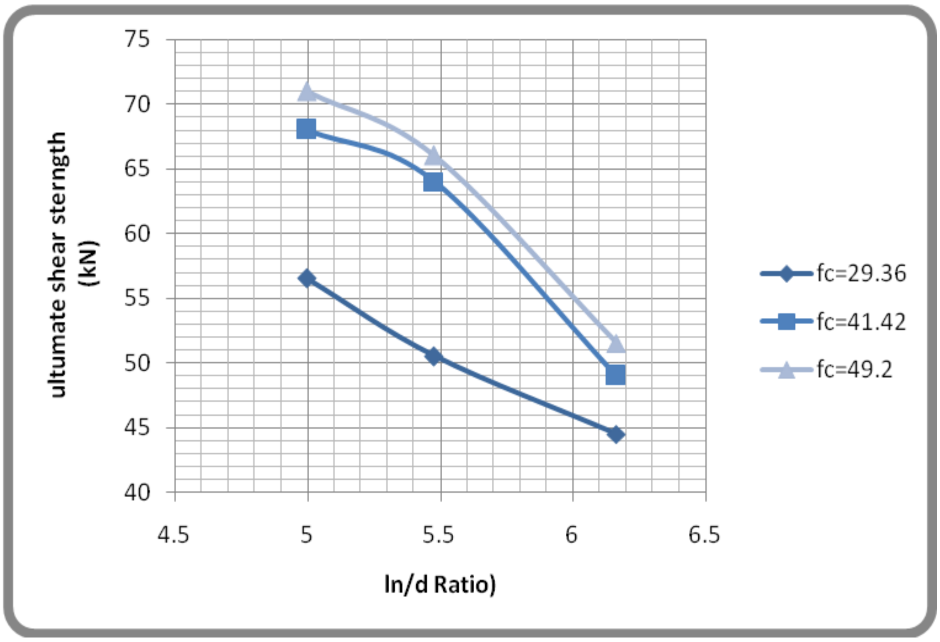

Fig. (9) Effect of clear span to the effective depth ratio (ln/d) on the ultimate shear strength.

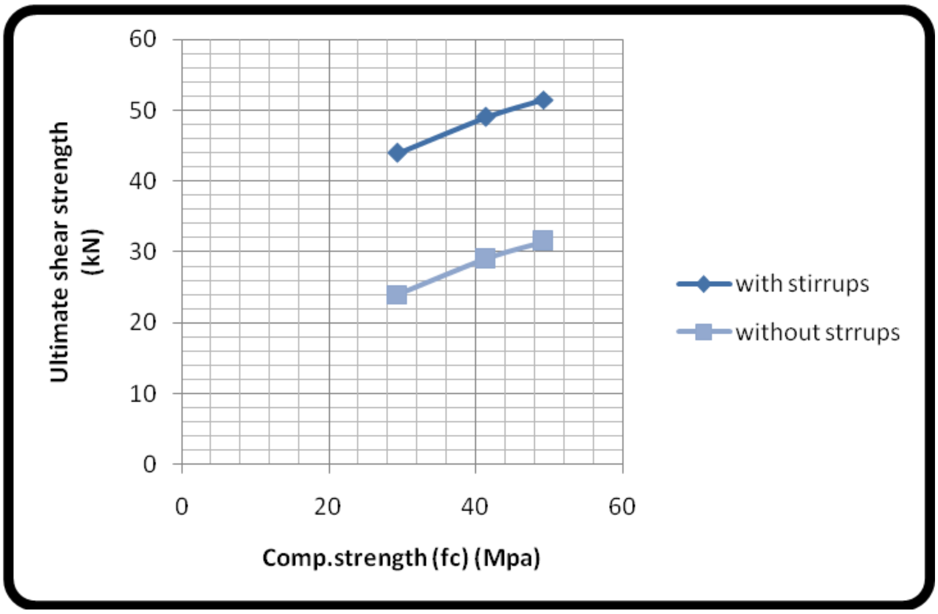

Fig. (10) Effect of absence of stirrups on the ultimate shear strength.

Table (5) effect of compressive strength (f'_c) on the percentage increased in the ultimate shear strength.

Group	Clear span to effective depth ratio (ln/d)	Compressive strength (f_c) MPa	Ultimate shear capacity (V_u) kN	Percentage of increased in shear capacity %
Without stirrups	6.164	29.36	24	-------
		41.42	29	20.833
		49.2	31.5	31.250
With stirrups	6.164	29.36	44.5	-------
		41.42	49	10.110
		49.2	51.5	15.730
	5.479	29.36	50.5	-------
		41.42	64	26.732
		49.2	66	30.69
	5.0	29.36	56.5	-------
		41.42	68	20.353
		49.2	71	25.663

Table (6) effect of clear span to effective depth ratio (ln/d) on the percentage increased in the ultimate shear strength.

Group	Compressive strength (f'_c) MPa	Clear span to effective depth ratio (ln/d)	Ultimate shear capacity (Vu) kN	Percentage of increased in shear capacity %
With stirrups	29.36	6.164	44.5	-------
		5.479	50.5	13.483
		5.0	56.5	26.966
	41.42	6.164	49	-------
		5.479	64	29.612
		5.0	68	38.775
	49.42	6.164	51.5	-------
		5.479	66	28.155
		5.0	71	37.86

Table (7) effect of absence of stirrups on the percentage increased in the ultimate shear strength.

Beams	Compressive strength (f'_c)Mpa	Ultimate shear capacity (Vu)kN	Percentage of increased in shear capacity %
A10	29.36	24	-------
A11	29.36	44.5	85.41
B10	41.42	29	-------
B11	41.42	49	68.96
C10	49.2	31.5	-------
C11	49.2	51.5	63.492

6. Conclusion

Base on the results of this experimental investigation , the following conclusions are drawn:

1. The ultimate shear strength predicated from ACI 318-08 equations is lesser than the experimental values of the present work.
2. The clear span to the effective depth ratio (ln/d) has a significant influence on the ultimate shear strength, the ultimate shear strength of SCC beams increased about 29.966%,38.775%and 37.85% when the clear span to the effective depth (ln/d) decreased from (6.164 to 5.0) at compressive strength (f_c') 29.36, 41.42 and 49.2 Mpa respectively .
3. The ultimate shear strength of SCC beams with stirrups increased at decreased rate when the compressive strength (f_c') increased, The ultimate shear strength increase about 15.73%.30.69%and 25.663% when the compressive strength(f_c') increased from (29.36 to 49.2 Mpa) at clear span to effective ratio (ln/d) 6.164, 5.479 and 5.0 respectively.
4. The ultimate shear strength of SCC beams without stirrups increased when the compressive strength increased, the ultimate shear strength increased about 31.25% when the compressive strength increased from 29.36 to 49.2 Mpa.
5. The ultimate shear strength of SCC beams with stirrups is greater than SCC beams without stirrups, the ultimate shear strength of SCC beams with stirrups increased about 85.41%, 68.96% and 63.492% as compared with ultimate shear strength without stirrups at compressive strength 29.36, 41.42 and 49.2 Mpa respectively.

Fig (11) crack pattern of SCC beams

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